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# ANALYTICAL/EXPERIMENTAL INVESTIGATION OF CORPUSCULAR RADIATION DETECTORS

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DARPA PROGRAM DIRECTOR: US ARMY MAJOR G. P. LASCHE', PhD





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Approved by: Dennis Kretzschmar
Dennis Kretzschmar,
Program Manager, Raytheon Co.



RAYTHEON COMPANY
SUBMARINE SIGNAL DIVISION
PORTSMOUTH, RHODE ISLAND 02871

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This document is the first quarterly technical report on the Analytical/Experimental Investigation of Corpusuclar Radiation. It describes the progress made in efforts to identify a sensor with proper signal to noise ratio to detect corpuscular radiation, design that sensor, and perform an experiment.

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This quarterly report has been prepared by Mario D. Grossi, Principal Investigator, with inputs from all members of the program team. For each section, credit is given to the writer who contributed it.

## Executive Summary

Four methods potentially usable in the detection of low-energy neutrinos were investigated during ~~the first quarter~~ this of project activity. The magnetic interaction approach and the metal-grain calorimeter (the two methods that were discussed in Raytheon proposal to DARPA of November 1983 and in follow-on amendments) are the approaches on which the effort mostly concentrated. However, we have also analyzed two new methods, one based on the interaction between neutrinos and superconducting electrons, and another based on a bolometric scheme that uses a silicon target.

Raytheon investigation is performed with the aim of planning and conducting feasibility demonstrations with such method(s), among the four possibilities above, that will emerge as most promising from the initial study phase. We have already reached a conclusion concerning the approach based on the neutrino/superelectron interaction, ~~We have~~ it was decided, based on the initial analysis, to discontinue the study of this method because it does not hold sufficient promise to reach maturity within the strict constraints, time-wise and money-wise, of the present contract to Raytheon. Of the remaining three approaches only two were, and continue to be, scheduled to undergo laboratory tests as a part of the Raytheon program: the magnetic sensor and the metal-grain calorimeter. As far as the silicon bolometer is concerned, ~~we limited our~~ is limited activity to an analytical effort, primarily because of lack of adequate funds. The relative emphasis presently given to each of the three approaches above could, however, change, and we could start doing laboratory work on the silicon bolometer (at the expenses of one or both of the other two approaches) if the findings of our continuing study indicated that this is an advisable programmatic step to undertake.

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At the completion of the first quarter of project activity (the date of this report), the status of the two prime contenders is as follows. The magnetic interaction approach has still some theoretical points to be worked out (and we are active at solving them). However, its mechanization is particularly simple, uses mostly off-the-shelf equipment, and it could be ready for a laboratory experiment at an earlier time than all the other sensors that we have under investigation. The foundation of this approach is the weak interaction between a current of low-energy neutrinos and a single unpaired electron in the target. Such an interaction implies an elastic scattering of neutrinos from electrons, an effect that has been observed using reactor neutrinos. Stodolsky (1975) considered its application to the detection of cosmic neutrinos by a large sample of polarized electrons. There is a neutrino-induced torque on the electrons, that is transmitted to the lattice, similar to the torque exerted on a bar magnet by a uniform external magnetic field. In our investigation, we are following Bramanti (1984), who suggested to detect the magnetic signal (and not Stodolsky's mechanical signal) resulting from the interaction of the neutrino current with a polarized or unpolarized target made of high-permeability material. The instrument consists of a SQUID magnetometer, "loaded" with a high-permeability interaction target. We expect that this instrument will provide directional information in the sensing of the neutrino beam, and will be able to distinguish antineutrinos from neutrino flux. FERMILAB's Dr. M. Kuchnir is scheduled to perform the measurement of the overall thermal noise of this target (mounted inside a 4°K SQUID cryostat), as early as Fall 1985.

The metal grain calorimeter, also known as Superheated Superconducting Colloid (SSC), is characterized by simpler theoretical foundations (Drukier and Stodolsky, 1982). It is based on neutrino/nucleus scattering, that causes energy deposition by the neutrino beam on the metal grains (the grains have a

diameter of a few micrometer and are made, for instance, of tin). The grains are suspended in a colloid, are kept at about 3°K (when made of tin) in a superheated superconducting state, change state because of neutrino-induced heating, and flip-over to normal. A superimposed magnetic field, whose lines of force were forbidden from entering the superconducting grains by the Meissner effect, may now penetrate in the granules. A magnetic signal results, and this signal can be picked-up with a SQUID magnetometer or with another equivalent magnetic sensing approach. There is a wealth of experimental data on the use of the metal-grain calorimeter for the detection of electrons, gamma rays, and neutrons. Although attempts at detecting neutrinos with the SSC calorimeter have been not yet performed, this wealth of experience is an important point in favor of the SSC approach. The technology, however, to produce a suitable sensor is not straightforward and the difficulties in implementing this scheme are several. One is the fact that any form of heating of the grains makes them flip-over, not just the neutrinos. Therefore shielding the instrument from e.m. waves and particles is a very stringent requirement. In addition, the level of residual radioactivity in the grains must be very low, and this requires the application of the ingot from which the grains are made of "zoning refining" techniques. This consists of eliminating impurities by travelling melting zone in the ingot, as it is currently done in the semiconductor industry with germanium and silicon ingots. In our case, we must apply it to ingots of tin, or aluminum, or lead.

The impurities problem is alleviated substantially in the silicon bolometer approach to neutrino detection, as described by Cabrera, Krauss and Wilczek (1985). This approach is based on elastic scattering of neutrinos by electrons in a crystalline silicon target kept at 1 to 10 milli °K (dilution refrigeration is therefore required for this approach, and this is not a point in favor of the

method). The result is a measurable temperature change in macroscopic amounts of material. The thermal pulses associated with an event are expected to be observable, based on the change of state to normal of superconducting tungsten rings deposited onto the silicon slab. They flip-over when they are heated as a consequence of the neutrino/electron interaction, and their change of state is sensed with a SQUID. Slabs of silicon with a particularly low level of residual radioactivity are routinely available from the semiconductor industry. The silicon bolometer appears very promising for neutrino detection. We would give to it a higher priority, if it would not be for the fact that the entire scheme has never been implemented, and consequently it could not be readied within the constraints of the Raytheon contract. In fact the only mechanization reported in the literature is the single-crystal silicon wafer where a thermometer is ion-implanted on the wafer's surface (Mosely et al., 1984; McCammon et al., 1984). A thermometer based on the tungsten ring approach, with SQUID read-out, has never been tested.

Concerning the feasibility tests that Raytheon is contractually obligated to design and conduct, our present thinking, after three months of program activity, is that a firs series of tests could be carried out by Raytheon at LANL, Los Alamos, NM, with the magnetic sensor, by using a source of low-energy neutrinos LANL's Tritium System Test Assembly (TSTA). This is a 150 gr tritium source divided in ten blocks of 15 gr each (when the tritium in the plumbing is also accounted for). Each block is in a 5 gallon container and the 10 containers could be arranged in a single layer wall (distributed planar source), double layer wall or in some other geometry. The wall could be mounted in a dolly that could be cyclically moved, back and forth with respect to the sensor, between the minimum achievable distance (a fraction of a meter) and a range of several meters, thus achieving for each cycle a peak-to-peak flux change larger than a

factor of ten. The movable wall could stay on each of the extreme positions for several seconds (or even minutes). The long-period, narrow-band, "square-wave" signal, expected to be present at the output of the SQUID, would be recorded on tape. We could then play back the tape and integrate hours of observation, in order to extract the signal from the noise. The sensor could be isolated from vibrations and mechanical oscillations with simultaneous use of several provisions, such as a suitable design of the target and of its coupling to the SQUID, and with vibrations abatement techniques that members of Raytheon investigator team have developed in the course of their previous research on gravity radiation antennas and gravity gradiometers. On 27 August 1985 Raytheon visited LANL at Los Alamos, NM. The group included the Program Manager, the Principal Investigator, the Program Scientific Advisor (Prof. R.R. Lewis of University of Michigan) and two Raytheon engineers. Several possible neutrino sources were discussed at LANL, during the visit and in several telephone conferences afterwards (Dr. G.P. Lasche', DARPA Program Director, attended the 8/27/85 meeting). At the time of writing of this report, it would appear that TSTA offers the best opportunity. On 28 August 1985, Raytheon visited NTS, Las Vegas, NV. The complexity and the obviously large cost of a feasibility test at NTS, using an underground fission detonation as an impulsive neutrino source, are such that in Raytheon's view, an experiment at LANL should be tried first, as perhaps the only realistic undertaking within the time and funding constraints of the Raytheon contract (we expect that the magnetic sensor will be available well on time for these tests). The magnetic sensor could then be moved to NTS in follow-on phases of the project, after the LANL-TSTA data have been reduced, processed, analyzed and interpreted.

For the SSC calorimeter, and for the silicon bolometer, an experiment design with identification of the usable neutrino sources was initiated, but not

yet completed. We will report on our findings concerning this point with our next quarterly report. However, Raytheon expects that with each one of these two approaches the time required to prepare for an experiment will be found longer than the time to prepare for feasibility tests with the magnetic interaction sensor.

# 1. INTRODUCTION

The main focus of Raytheon proposal to DARPA was on pointing out the potential usefulness to low-energy neutrino detection of techniques that had been developed by gravity radiation antenna designers and high-sensitivity gravity-gradiometer developers, techniques that were available to the Raytheon team. The Company's view was that the know-how acquired in the measurement of extremely weak forces and torques was offering a realistic hope to detect the momentum transfer from low-energy neutrinos to an interaction target (see Grossi, 1982, for background information on the applicability to neutrino detection of these techniques). This is why Raytheon, a Company that has always invested heavily on research but that had never been involved before in neutrino-related programs, felt that there was something valuable here to offer to DARPA, in the DoD quest for these elusive particles. The techniques that were proposed had originated in a community foreign to neutrino physics, nevertheless the potential for a contribution was clearly recognizable. A success would pave the way for the use of small-size, low-weight neutrino sensors in several applications of interest to DoD, spanning from Arms Control to ASW. The interest of the scientific community would also be substantial, considering, for instance, the research value to astrophysics and cosmology that the detection of solar neutrinos and cosmic neutrinos would have.

The first Raytheon proposal to DARPA was document P2463, dated October 1983. Earlier Raytheon program development efforts were a proposal to US Navy dated November 1980, and several viewgraph presentations that were given, respectively, to ONR on 8/17/81 and 10/5/81, to NRL on 1/19/82, and to DARPA on 7/7/83. The October 1983 proposal introduced the team that is active today in the contract granted to Raytheon by DARPA/AFOSR: 1) Raytheon Submarine Signal Division; 2) Smithsonian Astrophysical Observatory (SAO), with their expertise

in gravity-radiation antennas and high-sensitivity gravity gradiometers (see Fuligni and Grossi, 1984); 3) Prof. Robert R. Lewis, University of Michigan, with a strong interest and long-term involvement in low-energy neutrino detection research.

While Raytheon proposal P2463 was under review at DARPA (contract was awarded about 18 months after submittal), there were several conceptual and programmatic developments. First, Bramanti (1984), now a member of the SAO team, proposed that the momentum transfer neutrino/target should be measured by detecting the magnetic signal arising from the action of the torque on the spins of non-polarized electrons, rather than by detecting the mechanical effects (angular rotation) on a polarized target, as suggested by Stodolsky (1975). Second, because of the neutrino physics background of Prof. R.R. Lewis, University of Michigan (Scientific Advisor, Raytheon neutrino program) and of Dr. F. Gualtieri, Raytheon Submarine Signal Division Scientist (the Program's Deputy Technical Director), Raytheon felt confident in adding to the investigation the study of sensors other than the momentum transfer detectors. This was the reason why we could add the study of the SSC calorimeter (Drukier and Stodolsky, 1975), of the neutrino bolometer (Cabrera, Krauss and Wilczek, 1985), and the neutrino/superelectrons interaction sensor, proposed and investigated by Fuligni (a member of the SAO team, on leave from IFSI-CNR, Frascati, Italy). The probability of success of the overall Raytheon program is obviously enhanced by bringing in additional and totally different techniques, potentially usable in neutrino detection. Of special interest appeared bringing into the project the superheated superconducting colloid (SSC) sensing approach, developed by the Max Planck Institut (MPI) für Physik und Astrophysik, in Munich, West Germany. This is what we did, with DARPA prior approval, and SAO hired in June 1985 Dr. A.K. Drukier, of MPI, to work for the duration of the project, at the Observatory in

Cambridge, Massachusetts. Laboratory measurements with a prototype of a metal-grain calorimeter, are already underway at the University of British Columbia (UBC), Vancouver, BC, Canada, with funding provided by a subcontract from SAO, and under Dr. Drukier's supervision. UBC was chosen as subcontractor to SAO, at the recommendation of Dr. Drukier. Another subcontract has been let by SAO to FERMILAB, Batavia, Illinois, under the supervision of Prof. A.E. Lilley (Head of the neutrino program efforts at SAO) and of Dr. D. Bramanti. FERMILAB's Dr. Moyses Kuchnir will perform tests on the magnetic interaction target, concentrating on the measurement of the target's thermal noise. Dr. Krauss, Dr. Cabrera and Dr. Wilczek are also being hired by SAO as Consultants, to provide direct insight on their sensor, to further develop conceptually their bolometric approach, and to review, for the Director of SAO, the theoretical findings of the group.

In the following sections, each member of the investigation team illustrates the activity that was carried out during the first quarter of contract performance.

# 2. TECHNICAL DISCUSSION

## 2.1 Source Strength and expected flux

### 2.1.1 Model of neutrino burst from underground detonation of fission device (*)

This section is based on the study of a proposal by Herald Kruse and Rosalie Loncoski (LASL memorandum, Oct 1979) to detect antineutrinos from an underground explosion using a large liquid scintillater. Their estimates of the neutrino flux were based on a data bank of fission products ENDF/B-IV; a summary of the current version of these data (dated April '84) was provided by H. Kruse.

Their results are derived from an extensive and complex analysis of the anti-neutrino spectrum from a fission device and include the cascading effect of many decay chains, Fig. 1 shows their result, giving the number of $\bar{\nu}$ per second per fission, normalized to a total production of 6.1 $\bar{\nu}$/fission. This normalization is well established for fission reactors and is assumed to be correct for explosions as well.

Fig. 2 shows a simple model fit to their initial value and slope

$$Q(o) = \frac{1}{2}\gamma N = 0.45 \qquad -\dot{Q}(o) = \frac{1}{3}\gamma^2 N = 0.17$$

or therefore

$$\gamma = 0.57 \text{ sec}^{-1} \qquad N = 1.59\ \bar{\nu}/\text{fission}.$$

We have simplified our model further by letting $\gamma_o \to 0$ ; the above result corresponds to a uniform distribution of half lives from 1.22 sec to $\infty$.

In Fig.2 we have tabulated the function

$$Q(t) = N\gamma \left\{ \frac{1 - (\gamma t + 1)e^{-\gamma t}}{(\gamma t)^2} \right\}$$

In Fig. 3, the same results are plotted on a linear graph for shorter times to illustrate our signal shape.

(*) Contributed by R.R. Lewis

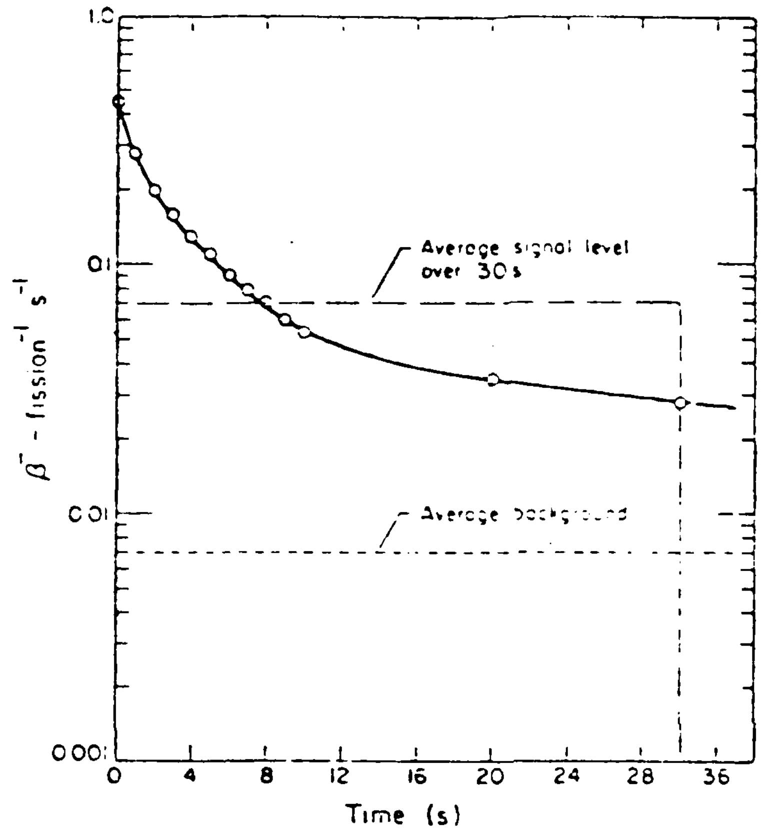



Fig. 1 Anticipated shape of counting rate vs time, in relation to desired background level.

(from Herald Kruse
and Rosalie Loncoski

Neutrino Proposal II

P-14-79-U-287

Oct 3, 1979)

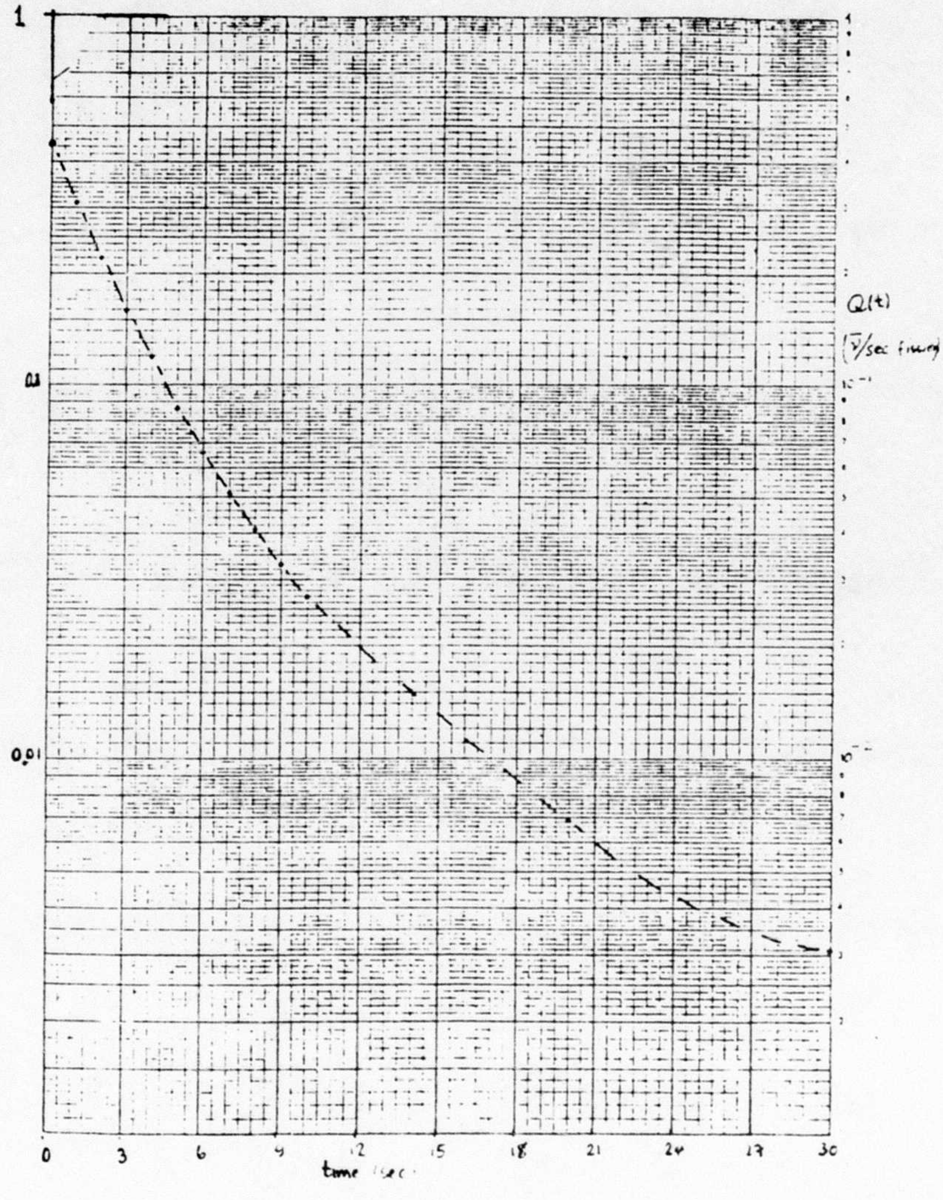



Figure 2

Plot of the function Q(t)

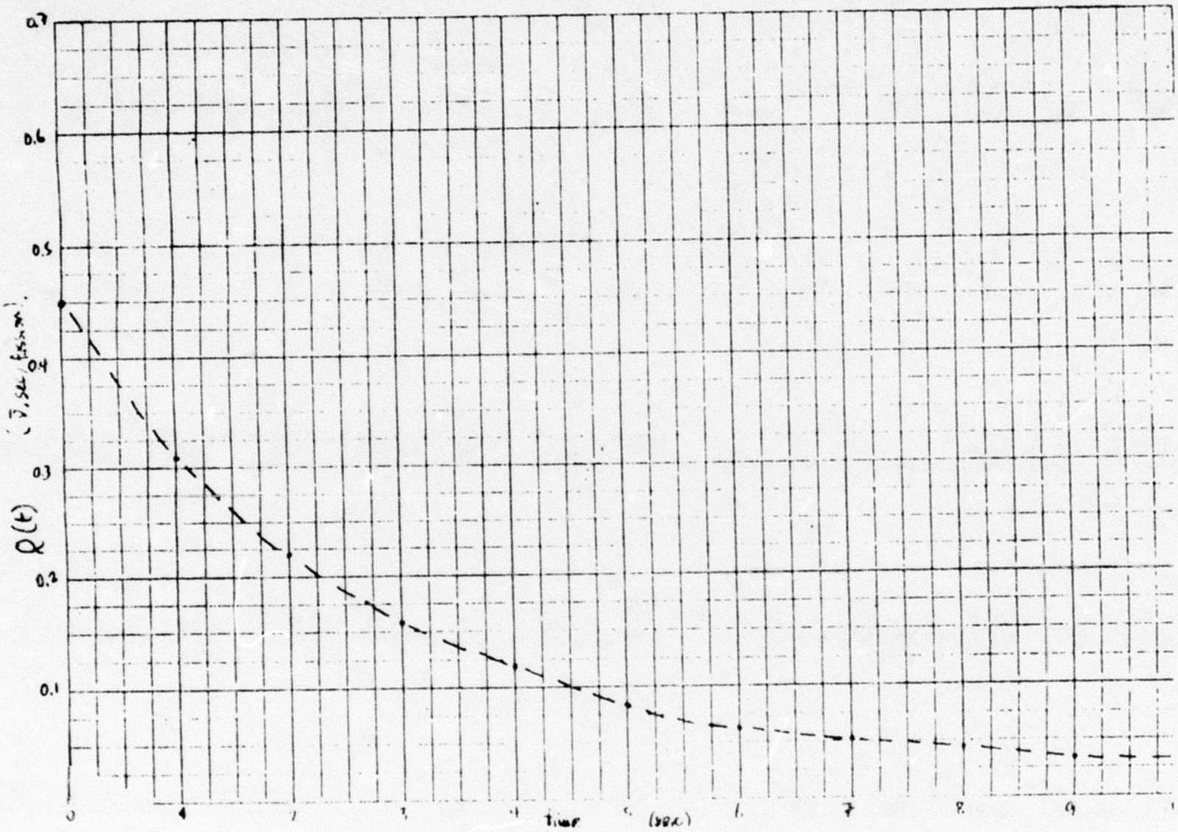
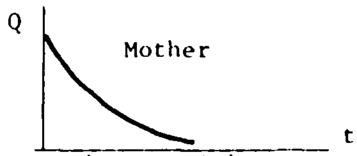


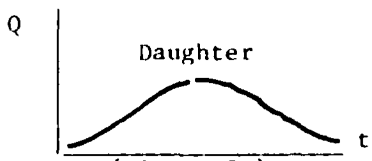
Figure 3
Approximate line shape of neutrino
signal

The line shape of a primary fission fragment is an exponential decay law as indicated In Figure 4.




(Figure 4.)

For a secondary fragment (daughter) it would be as indicated in Figure 5.




(Figure 5.)

This confirms the well known observation that daughters mature later than their mothers, and are less (radio) active at early times.

These numbers for Q (+) correspond to a yield of $\approx 2$ $\bar{\nu}$/sec with a lifetime $\approx$ 1 sec. The short-lived isotopes are present in the fission fragment distribution, but with relatively small percentage yield. The LASL results show that the spectrum is dominated by somewhat longer half lives, and lower energies.

We conclude that an acceptable estimate of the neutrino flux during the first second is

$$Q \Delta t \cong 0.4 \; \bar{\nu}/\text{fission}$$

and for a 150 Kton device

$$\left( 0.4 \; \frac{\bar{\nu}}{\text{fission}} \right) \left( 1.4 \times 10^{23} \; \frac{\text{fission}}{\text{kton}} \right) (150\text{ktn}) = 8.4 + 10^{24} \bar{\nu}$$

In the first second, the flux $\phi$, at 1/2 Km distance from the source, is therefore:

$$\phi = \frac{8.4 \times 10^{24}}{4 \pi (5 \times 10^{4})^{2}} = 2.67 \times 10^{14} \; \frac{\bar{\nu}}{\text{Cm}^2}$$

This agrees within a factor of two with LANL estimate of a flux of $\sim 5 \cdot 10^{15}$ $\bar{\nu}/\text{cm}^2$ (under comparable conditions) when the integration time is 30 seconds.

### 2.1.2 Model of Tritium System Test Assembly (TSTA) at LANL

This is a 150 gr tritium source ( it had a total strength of 5 Megacurie in late 1982 and we assume here that the strength is approximately the same) divided in 10 blocks of 15 gr each ( when the tritium in the plumbing is also accounted for). Each block is in a 5 gallon container and the ten continers ( each containing a source with strength of about 0.5 Megacurie) could be arranged in a variety of geometries, one of which could be in two groups of five blocks superimposed, each group in two horizontal rows, adjacent, respectively with 3 and 2 blocks (see Figure 6 ). The flux that we can expect at a distance of 1 meter can be computed as follows, under some simplifying assumptions

$$\phi \cong 2 \times \frac{q}{4\pi} \left( \sum_{n=1}^{3} \frac{\cos \alpha_n}{d_1^2} + \sum_{n=4}^{5} \frac{\cos \alpha_n}{d_2^2} \right) \bar{\nu}_e / \text{cm}^2 \text{ sec}$$

where:

$$q = 0.5 \text{ Megacurie} \cong 1.7 \quad 10^{16} \ \bar{\nu}_e/\text{sec}$$

$$d_1 = 100 \text{ cm}$$

$$d_2 = 120 \text{ cm}$$

$$\alpha_2 = 0^{\circ}$$

$$\alpha_1 = \alpha_3 = 26.56^{\circ}$$

$$\alpha_4 = \alpha_5 = 11.77^{\circ}$$

Therefore, we have:

$$\phi \cong 10^{12} \ \bar{\nu}_e/\text{sec cm}^2$$

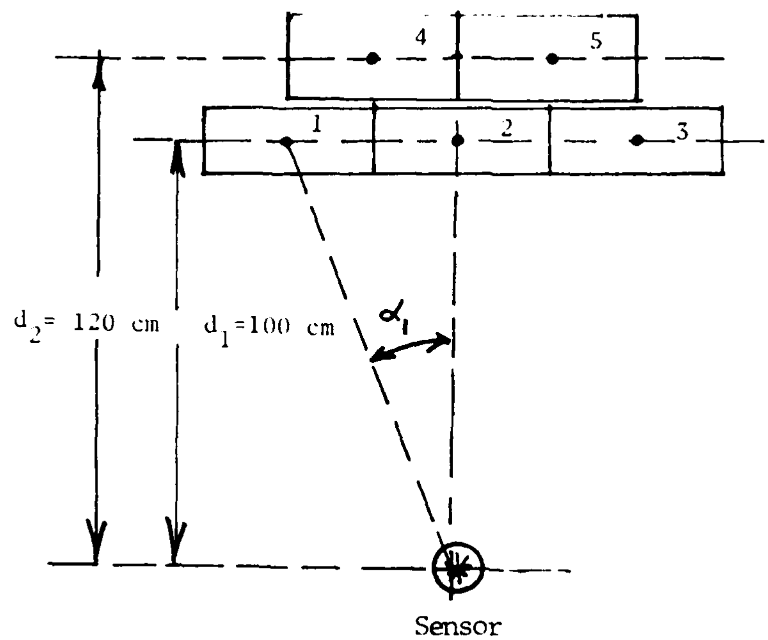



Figure 6
Top View of one group of five blocks

## 2.2 Detection Approaches Under Investigation, and Results Achieved Thus Far

### 2.2.1 Magnetic Interaction Sensing Approach

#### 2.2.1.1 Theoretical Foundations (*)

Our investigation includes the study of a method of detecting neutrinos , that is based on the classical properties of the weak neutral current interaction of

(*) Contributed by R.R. Lewis

neutrinos with the electrons in a magnetic material. In what follows, I will try to present an elementary discussion of the principles of this method, emphasizing the physical meaning of each result rather than presenting a long derivation. Instead of giving the numerical values of the various parameters which occur, we will stress the physical origin and meaning of these relations.

The method is based on the juxtaposition of three relations, which will be presented at the outset and then discussed in detail. The basic relations are:

$$\mathcal{H}_{weak} \cong \frac{G_F}{\sqrt{8}} \int d^3x \, (\bar{\psi}_e \gamma_\mu \gamma_5 \psi_e)(\bar{\psi}_\nu \gamma_\mu (1+\gamma_5) \psi_\nu) \tag{1}$$

$$\cong \sqrt{2}\, G_F \, \vec{\sigma}_e \cdot \vec{J}_\nu / c \cong \mu_B \, \vec{\sigma} \cdot \vec{H}_{eff}$$

$$\Delta \vec{B} = \mu \vec{H}_{eff} = \left(\frac{\mu}{\mu_B}\right)\left(\sqrt{2}\, G_F \, \vec{J}_\nu / c\right) \tag{2}$$

$$\Delta \Phi = N \, \Delta \vec{B} \cdot \vec{A} \tag{3}$$

First Formula

The first of these relations is simply the weak interaction between a current of neutrinos and a single unpaired electron in the target, which we will understand to be a soft magnetic material. Such an interaction implies the elastic scattering of neutrinos from electrons, which has been observed

using reactor neutrinos, by Reines and Gurr. $G_F$ is the measured Fermi coupling constant which characterizes the strength of this interaction. This interaction was also discussed by Leo Stodolsky, (1975) who considered its application to the detection of cosmic neutrinos by a large sample of polarized electrons.

At the time of Stodolsky's paper, the origin of this interaction was known to arise from the exchange of charged intermediate vector bosons but he could only speculate that neutral vector bosons might also contribute. Today we know from high energy scattering experiments that both charged and neutral bosons are exchanged in weak interactions and that the coupling strengths are consistent with the Glashow-Weinberg-Salam model. It is relatively safe to extrapolate this model to lower energies; the major unknown in this extrapolation is the neutrino mass. We will neglect the effect of mass for neutrinos of energy above 1 MeV, since neutrino masses, if they are in fact non-zero, are known to be much smaller than this energy. Hence, with these two caveats, we can claim that the interaction in (1) is a well known part of the successful electroweak model of GWS.

For high energy scattering experiments, one is interested in matrix elements of this interaction between in and out states of the neutrino with <u>different</u> momenta, since those experiments detect scattering reactions with a substantial momentum transfer. On the contrary, we will consider instead matrix elements with the <u>same</u> momentum before and after. Indeed, we will consider the classical limit in which the neutrino current density is large and fixed, uniform in space and constant in time. In this limit, the neutrino current density is simply replaced by a constant. Later, we will let the current vary in time, but only on a macroscopic timescale (microseconds) not on an atomic or nuclear timescale. The contributions of a large number of neutrinos are additive but

only in the sense of adding intensities, not amplitudes. For this reason, we use the word "classical" not "coherent". We will also assume additivity of the contributions of the many electrons in the target.

Finally, we have also made a non-relativistic reduction of the electron current operator, keeping only the space components of the axial current. This is appropriate for a collection of slowly moving electrons in ordinary condensed matter. The result is an interaction between the neutrino current and the electron spin, of exactly the same form as the interaction between an electron and an external magnetic field.

Stodolsky reached the same conclusion in a somewhat different way, by considering not one stationary electron in a current of neutrinos, but one electron moving slowly through a collection of neutrinos with average momentum zero. Clearly, these two points of view differ only by a Galilean transformation of the coordinate frames.

Stodolsky emphasized the mechanical effect of this interaction on a polarized sample of electrons: there would be a torque exerted on the electrons, which would be transmitted to the lattice, exactly as there is a torque exerted on a bar magnet by a uniform external magnetic field. He discussed the possibility of detecting cosmic neutrinos by measuring this torque, but concluded that it was unobservably small. Furhtermore, it would be nearly constant in time, and very hard to distinguish from a small magnetic field. Other authors (Cabbibo and Maiani, Langacker, Leveille and Sheiman) have re-analyzed this question using the more general method of the stress tensor, but have come to the same conclusion.

Donato Bramanti considered a different aspect of this same interaction: it should lead to a polarization and hence magnetization of an initially unpolarized

sample of soft iron. This idea suggests the use of magnetic detection, rather than mechanical detection.

Second Formula

Relying on the analogy of the weak interaction and the magnetic interaction by replacing the neutrino current with an effective exernal field, it follows that the response of the soft iron to the neutrino current is the production of a magnetic field throughout the sample. It is appropriate to denote the effective field as $H_{eff}$ is very small and it is proportional to the local value of the neutrino current rather than the more familiar action-at-a-distance of Ampere's Law.

It is essential to stress that the resulting field B inside the target is enhanced by a factor mu, the magnetic permeability of the soft iron. This is a very large factor which was missing in the mechanical response discussed by Stodolsky. It is also important to emphasize that B is an ordinary magnetic field, not an effective pseudomagnetic field like $H_{eff}$.

The mechanism for generation of this magnetic field is as follows. The torque exerted by the neutrinos on each electron will itself produce a weak polarization of the electron spins. This polarization would lead to a magnetic field, but not enhanced by the factor mu, which is a material constant characterizing the condensed matter, not just the independent electrons acting individually, as in a dilute gas. There is no further weak correction to this polarization in condensed matter, since the weak interaction between electrons has short range compared to the atomic separation. However, there is an electromagnetic correction, due to the long range magnetic interaction between the polarized electrons. Thus, the weak polarization of the electrons produces a magnetization in the iron, which in turn enhances the polarization of the eletrons, exactly as the polarization due to an external magnetic field would be enhanced.

The magnetic permeability which enters is clearly the differential permeability (i.e. the slope of the B vs H curve), since the $H_{eff}$ will always be a small perturbation on the existing H due to stray sources.

We have verified the correctness of this mechanism with a derivation of a much simpler problem: the magnetic field induced in a dilute sample of spins interacting only with the current of neutrinos and with each other through some unspecified spin dependent coupling. This is only a "toy model" for the real system of interest, but it illustrates the above discussion.

Third Formula

The third relation is the ordinary formula for the Faraday induction of a flux through a coil of N turns enclosing the target. We have included it simply to stress that it is this flux which we propose to measure, using a SQUID.

Conclusions

The main problem in detecting neutrinos is to overcome the very small value of the weak interaction constant $G_F$. As is evident in the above relations, we have five independent means of compensating the small value of this parameter:

1. The SQUID is sensitive to individula flux quanta.
2. The neutrino current density is very large.
3. The magnetic permeability mu can be very large.
4. The area of the target can be made large.
5. The number of turns N can be made large.

Our task is therefore to consider each of these factors carefully, increasing the sensitivity to neutrinos to the limits of current technology. Success appears possible, at least on paper, but an experimental demonstration is clearly needed.

2.2.1.2 Instrument Configurations Under Considerations for Magnetic Sensors*

2.2.1.2.1 General Remarks

According to the weak-interaction theory a uniform neutrino flux $J_\nu$ produces a torque on the magnetization electrons in a ferromagnet. On single electrons this effect is equivalent to a weak external magnetic field

$$H_{eq} = \frac{\sqrt{2}G_F}{2c\mu_\beta} \cdot J_\nu$$

with

$G_F = 1.43 \times 10^{-49}$ erg $cm^3$ (Fermi constant)

$c = 3.10^{10}$ cm $sec^{-1}$ (Speed of light)

$\mu_\beta = 9.27 \times 10^{-21}$ erg $gauss^{-1}$ (Bohr magneton)

In the case of a polarized hard ferromagnetic substance (an ordinary magnet, with low $\mu$ and high $H_c$) the orientation of the electron spins is fixed with respect to the lattice. Therefore the effect will lead to a mechanical torque on the whole magnet (like for a compass needle) (Stodolsky, 1975).

A much more direct effect of the $\nu$-flux should be to induce, or to change, a magnetization in a soft ferromagnetic substance, where the electron spins are relatively free to change their orientation with respect to the lattice (low $H_c$ and high $\mu$) (Bramanti, 1984).

*Contributed by D. Bramanti

High $\mu$

The energy deposited in the target as magnetic energy is $\Delta E_{magn} = \frac{1}{2} \mu H_{eq}^2$, and is the only detectable with this method. Due to the smallness of $H_{eq}$, even if we use ferromagnetic substances with very large $\mu$'s (for example $\mu \sim 10^{10}$) this $\Delta E_{magn}$ is only a very small part of the total energy $\Delta E$ available in the $\nu e^-$ interaction.

Many ferromagnetic substances, for example wires under longitudinal stress, or previously strained and/or heath treated in longitudinal magnetic fields (Figure 7), can have hysteresis cycles with practically vertical sides, corresponding to a $\Delta\mu \rightarrow \infty$ if we operate in the steepest parts of it. It is also possible to obtain metastable magnetic situations, leading to avalanche magnetic effects. In these last cases the $\Delta E_{magn}$ would be only the trigger of a much larger and detectable signal: but only laboratory tests can tell us how many orders of magnitude in the signal we should be able to gain with these methods. Note that these avalanche effects are themselves directional so that the directional sensitivity of the device would be maintained.

In Figure 7 we can see how the hysteresis cycle of soft ferromagnetic substances can be changed by various treatments. Compare especially Figure (c) with (d), in 7.

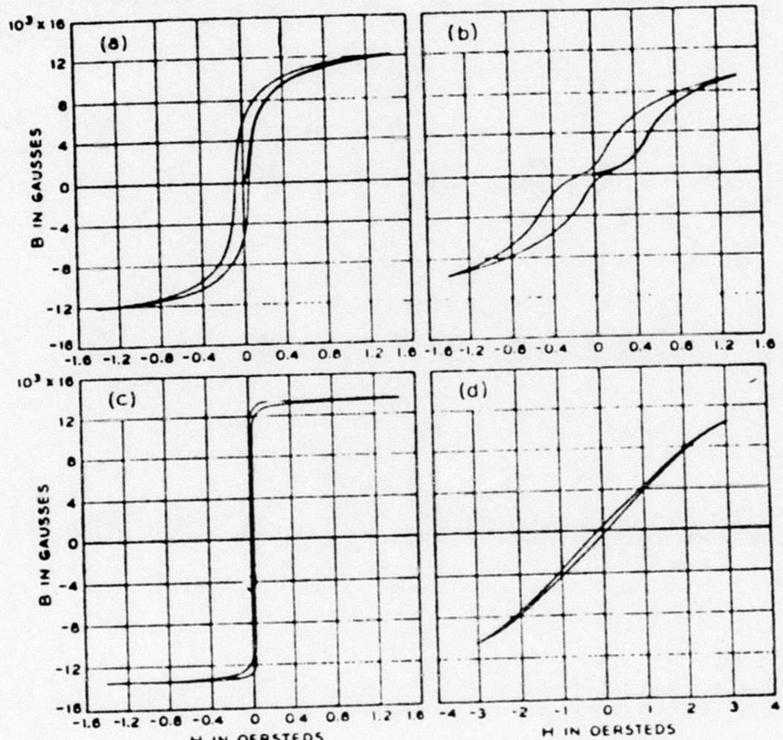



Figure 7- Hysteresis loops of 65 Permalloy heat-treated in various ways: (a) annealed at 1000°C; (b) baked at 425°C for 24 hours, (c) heat-treated in a longitudinal field; (d) heat-treated in a transverse field.

FROM: BOZORTH, FERROMAGNETISM, VAN NOSTRAND (1951, p. 499).

## Weiss Forces

Ferromagnetism is characterized by magnetic domains due to the so called Weiss forces: they are short range spin-spin forces among the electrons, that oblige the spins to be all parallel in each domain but do not prevent them to rotate all together by the same amount. They are about 100 times stronger than magnetic forces and involve energies of the order of $10^{-2}$ eV to flip one electron against them (each domain can contain $10^{10}$-$10^{15}$ or more electrons). Therefore in the study of weak interactions at low energies ($< 10^{-2}$eV) between the $\nu$-beam and the target electrons in a magnetic domain we cannot consider their spins independently, but we have to represent the process as an interaction between the $\nu$-beam and a kind of "total spin state" of the whole system of magnetization electrons in each domain.

## Coherence

Since the "magnetic" like effect of the neutrino beam on the electrons spins does not depend on the phase of the incoming neutrinos, it should be coherent in the whole domain even for $\Lambda_\nu$ smaller than the interatomic distances.

Both the above considerations should increase the interaction cross section by many orders of magnitude over the value calculated by Stodolsky and should lead to a much higher $H_{eq}$.

2.2.1.2.2 Sensitivity Analysis

It is not easy to calculate the sensitivity of the magnetic detector that we have proposed since the physical properties of low-energy neutrinos are not yet fully understood. So far almost all detection experiments have dealt with high energy neutrinos, mostly in nuclear reactions or in cases of very high energy scattering. It is not yet known what happens when a homogeneous low-energy neutrino flux ($E_\nu << m_e c^2$) interacts with a large number of oriented spins, all bound together in a kind of macroscopic spin state, as we have for example in a domain of a ferromagnetic substance. We might try to extend to this case Stodolsky's formula

$$\Delta E = \frac{\sqrt{2}\, G_F}{c} \cdot J_\nu \qquad (1)$$

which we may assume valid for single electrons in the homogeneous neutrino flux $J_\nu$. However we immediately run into difficulties because Stodolsky's effect, the rotation of the orientation of electron spins, does not depend upon the phase of the incoming neutrino wave. Therefore we should get an effect that is coherent in the whole interaction volume. However, this is not possible, because the incident plane wave representing the neutrino beam cannot undergo a net deflection inside a homogeneous target, even if the latter is polarized (a possible refraction at the surfaces of the target has already been shown by other authors to be negligibly small).

A net large deflection of a (small part of the) neutrino beam could be produced in the volume of a target which is non-homogeneous, like a crystal lattice (see for example the diffraction of neutrons by crystals, unmagnetized or magnetized). However this would be effective only for monochromatic neutrinos, so that, until we find a way to produce an intense and monochromatic beam

of neutrinos we cannot hope to detect them in this way.

Following Stodolsky, we could assume that the neutrinos are diffused incoherently by the individual electrons in the target. However, the average angle $\theta$ of diffusion, because of the weakness of the interaction, would be very small. The angular momentum transferred to the target electrons would be given by the change of the neutrinos total angular momentum parallel to their initial velocity $v_\nu$. This angular momentum changes by a factor of only $(1-\cos\theta) \simeq \frac{1}{2}\theta^2$, which is a second order effect, too small to be detected. However the latter assumption cannot be considered correct, because the electrons in a ferromagnetic domain are constrained to be all aligned in the same direction by the Weiss forces and cannot, therefore, be considered isolated scattering centers in low energy interactions involving their spins. On the other hand, low-energy neutrinos cannot be absorbed by the target and if, for what we have said before, they cannot be deflected either, this means that if they are massless particles with $v_\nu \equiv c$, and spin parallel $(\vec{\sigma}\uparrow\uparrow\vec{v}_\nu)$ or antiparallel $(\vec{\sigma}\uparrow\downarrow\vec{v}_\nu)$ to their velocity, they cannot possibly transfer angular momentum to the target, and therefore there is no resulting torque on it.

At this point, the only possibility left of obtaining a detectable non-zero effect seems to be the assumption that neutrinos are not massless particles. If this is so, their speed at low energy would be different from c but their high energy properties (with $v_\nu \sim c$) would remain almost the same. Their properties at low energy, on the contrary, could be drastically different. The most important consequence for our experiment is that their spins could take more than one orientation in space, and not just be only parallel or only antiparallel to their direction of motion. Therefore a polarized neutrino beam could exchange angular momentum coherently with the electrons in the whole volume of a polarized target even without being absorbed or deflected. In any case there would

be no need for the neutrinos to lose much energy since the energy needed to flip against the Weiss forces the electrons of the target could be provided almost entirely by placing them in a metastable magnetic situation. Actually, they could even gain energy in this process. If $E_\nu$ does not change, after a sufficiently long interaction path the polarization of the neutrino beam would be diminished, reduced to zero or even reversed, depending on the various initial polarizations in the interacting system. Similar effects could also take place for longitudinally polarized beams of other particles, but if they also possess a magnetic moment, like for example neutrons, their electromagnetic interaction will probably completely hide any weak interaction effect.

In order to compute the sensitivity of the magnetic detector, we can proceed as follows.

If we use

$$J_\nu = 10^{12}\ \bar{\nu}_e\ \text{cm}^{-2}\,\text{sec}^{-1} \tag{2}$$

we have from (1)

$$\Delta E = 6.76\text{x}10^{-48}\text{erg} = 4.22\text{x}10^{-36}\text{eV} \tag{3}$$

for one electron in the homogeneous neutrino flux $J_\nu$. In about 44.5 kg of Fe there are about $10^{27}$ oriented electrons (see Section 2.2.1.2.3 - Appendix) and if these electrons were considered independent one from the other, as suggested by Stodolsky, their total $\nu$-dependent energy in the flux $J_\nu$ would be the sum of their energies

$$\Delta E_{tot} = 10^{27}\ \Delta E = 4.22\text{x}10^{-9}\text{eV} \tag{4}$$

The energy (3) would be equal to the difference in energy between the two polarization of an electron in a magnetic field of intensity

$$B = \frac{\Delta E}{2\mu_B} = 3.6 \times 10^{-28} \text{ gauss} \tag{5}$$

or

$$H_{eq} = \frac{B}{\mu_o} = 3.6 \times 10^{-28} \text{ oersted} \tag{6}$$

where $\mu_B = \frac{e\hbar}{2m_e c} = 5.79 \times 10^{-9}$ eV gauss (Bohr magneton) and $\mu_o = 1$ in the c.g.s. e.m. system.

By integrating for $9 \times 10^4$ cycles (for example by displacing the TSTA source from 100cm to a few meters away, *once every 6 seconds for 6* days) we have $\Delta E_{intr} = 3.7 \times 10^{-4}$ eV.

A necessary condition for being able to detect the signal above the thermal noise is

$$\Delta E_{tot} > 1kT \tag{7}$$

and this would require in our case that $T \leq 4.2°K$.

If we use as high-permeability target the mass of 1 ton of Fe, we would need, when operating at 4.2°K an integration time of about $6\frac{1}{2}$ hours. However, $H_{eq} = \frac{\Delta E}{2\mu_\beta} = 3.6 \times 10^{-28}$ oersted and with $\mu_r = 3 \times 10^9$ (or $10^{10}$) we have $\Delta B \simeq 10^{-18}$ gauss (or $3.6 \times 10^{-18}$ gauss). If we then use a superconducting flux transformer with a primary of $10^3 cm^2$ cross section (cross section of the 1 ton

$F_e$ target) and a secondary of 0.1 $cm^2$, the gain is $10^4$ and the magnetic field to be measured is $\Delta B = 10^{-14}$ gauss (or $3.6 \times 10^{-14}$ gauss). With a commercial SQUID having a sensitivity of $10^{-12}$ gauss $cm^2/\sqrt{H_z}$ at 4.2°K, we would need an integration time of ~ 10 days (or 1 day with $\mu_r = 10^{10}$). With an advanced SQUID having a sensitivity of $10^{-13}$ gauss$\cdot cm^2/\sqrt{H_z}$, we would need an integration time of 3 hours (or 20 minutes, with $\mu_r = 10^{10}$).

Concerning our ability of obtaining a $\mu_r = 3 \times 10^9$ (or even $\mu_r = 10^{10}$), this is not, in principle, impossible, since practically-infinite values for $\Delta\mu_r$ have been obtained under particular conditions in various unstable (or metastable) magnetic phenomena. However, it is not clear, without experimental tests, whether all this could lead to the detection of such small effects. These experimental tests will be conducted at FERMILAB in Fall 1985.

A sensor configuration that appears promising for possible tests with TSTA at LANL is as follows:

1 ton target (a cube with ~ 50 cm side)

4.2°K cryostat temperature

| | |
|---|---|
| target material: | thermally treated supermalloy with differential $\mu_r = 3 \times 10^9$ (and possibly $10^{10}$) |
| Magnetic Bias: | target will be made to go into descending branch of hysteresis cycles and leave a value of H for which $B \simeq 0$. Superconducting coil will keep preset bias w/o power supply. |
| Flux concentrator = | gain $10^4$ |
| Magnetic shielding = | superconducting lead sheet wrapped around target |
| Read Out: | SQUID magnetometer |
| SQUID sensitivity: | 1 $\mu$gamma/$\sqrt{H_z}$ (possibly 0.1 $\mu$gamma/$\sqrt{H_z}$) |

2.2.1.2.3 Appendix

Electron spins in ferromagnetic domains*

Pure metallic iron can be taken as the typical example of a soft ferromagnetic substance, with a magnetic permeability $\mu_r$ reaching the value of $10^6$ or more and a low coercitive field $H_c \sim 0.02$ oersted or less. Its saturation magnetization is $B_s = 21580$ gauss at room temperature (and 21805 gauss at 0°K), corresponding to 2.218 Bohr magnetons per atoms. Since the gyromagnetic ratio for Fe is $g = 1.94$ we have that 94% of its magnetization is due to electron spins (for which $g = 2$) and only 6% to their orbital motions (for which $g = 1$). We are interested only in the spins, because (at least to the order of $\frac{v_e}{c}$) the neutrino flux should not have any influence on electric currents ($v_e \sim 10^{-13}c$) nor on atomic orbital motions ($v_e \sim \alpha c \sim \frac{c}{137}$). Therefore we have that, in Fe, $0.94 \times 2.218 = 2.085$ Bohr magnetons per atom are due to electron spins. The number of atoms per gram of Fe is

$$N/A_{Fe} = 1.08 \times 10^{22} \text{ atoms/gram}$$

where $N = 6.022 \times 10^{23}$ is the Avogadro number and $A_{Fe} = 55.847$ grams is the atomic weight of Fe. The density of Fe is 7.874 gr $cm^{-3}$ so that in a cubic centimeter there are $8.5 \times 10^{22}$ atoms, or $1.77 \times 10^{23}$ spins since the number of electron spins per gram of Fe is $2.085 \times N/A_{Fe} = 2.25 \times 10^{22}$ spins/gram. In 44.5 kg of Fe, with a volume of $5.65 \times 10^3$ cm, there are then $\sim 10^{27}$ electron spins. In the case of a large permanent magnet (as in Stodolsky's proposed experiment) where the magnetization is usually rather incomplete, due to technical difficulties in the magnetization process, a much larger mass is needed to have the same number of spins all oriented in the same direction. In single

*Numerical data taken from Bozorth, Ferromagnetism, Van Nostrand 1951 and from Rev. Mod. Phys. 56, April 1984.

magnetic domains, on the contrary, all spins are oriented in the same way by the spin-spin forces (the so-called Weiss forces). Magnetic domains can have dimensions ranging from microns to mm or cm depending on the way the material has been produced and treated, and also on externally applied magnetic fields: larger fields produce an increase of the volume of the domains oriented along the field direction. Fe domains in the range 0.1 ~ 1 mm will contain $N_e \sim 10^{17} \sim 10^{20}$ oriented electron spins. Although large magnetic domains are easier to obtain in the purest materials, (mostly alloys of known constituents without impurities) and in single crystals, there is actually no strong correlation between dimensions of Weiss domains and dimensions of single crystals: magnetic domains can be either larger or smaller than the monocrystals of which the material is made.

## 2.2.2 SSC Metal-Grain Calorimeter*

### 2.2.2.1 Low Temperature Neutrino Detectors, State-of-the-Art

The theoretical basis of the development of the new neutrino detector was given in a paper by A.K. Drukier and L. Stodolsky, "Principles and applications of neutral-current detector for neutrino physics and astronomy," Phys. Rev. D., December 1984, pp. 2295-2309. In the abstract of this paper we wrote:

"We study detection of MeV-range neutrinos through elastic scattering on nuclei and identification of the recoil energy. The very large value of the neutral-current cross section due to coherence indicates a detector would be relatively light and suggests the possibility of a true "neutrino observatory." The recoil energy which must be detected is very small ($10-10^3$ eV), however. We examine a realization in terms of the superconducting-grain idea, which appears, in principle, to be feasible through extension and extrapolation of currently known techniques. Such a detector could permit determination of the neutrino energy spectrum and should be insensitive to neutrino oscillations since it detects all neutrino types. Various applications and tests are discussed, including spallation sources, reactors, supernovas, and solar and terrestrial neutrinos. A preliminary estimate of the most difficult backgrounds is attempted."

In 1981, we realized that other low temperature techniques may be used to detect weakly interacting particles. In our Phys. Rev. paper we wrote:

"In this paper we have concentrated on the superconducting-grain method for observing the nuclear recoil in neutrino-nucleus elastic scattering. It is possible, however, that in view of the many difficult and often new technical problems involved that other techniques for observing this reaction may have to be considered also. These may include, for example, superconducting tunnel junctions, where the small energy to break a Cooper pair is exploited, or very-low-temperature thermometry with pure carbon or silicon where the very low heat capacity of these materials is used. This last alternative may be quite attractive since the great purity of the silicon and the potential for high-resolution calorimetry could considerably ease the problems of background suppression. In any event, our calculations of cross sections and rates, and considerations for the various tests and applications may be directly taken over, since the basic physics and energetics of the neutrino- nucleus are always the same. Similarly, the nature of the background and the principles for suppressing it will not be essentially different in other detection methods. We may return to some of these ideas in a further publication."

Independently of us, the idea of using silicon have been conceived by T.

*Contributed by A.K. Drukier

Niinikoski et al. (1983) and, later by B. Cabrera et al. (1984,1985). An interesting variant of detection using dielectrics is to look for ballistic photons.

In a series of seminars in 1983/1984 in MPI/TU, Munich, we studied the advantages and limitations of different low temperature techniques and concluded that SSC seems to be the best known technique. It is partially due to the fact that SSC can be tested in T > 1°K, whereas the studies of silicon detectors requires dilution refrigerators. More specifically, the SSC was tested as detector of minimum ionization particles and x-rays. The electronic read-out which permits to detect the change of state of a single grain developed by Orsay and TU, Munich groups. Some methods of grain production/selection have been studied by myself in MPI, Munich.

In collaboration consisting of scientists at MPI and TU Munich, West Germany (A.K. Drukier, R. Golub, L. Stodolsky, H. Oberlack, F. von Feilitzsch, R. Mössbauer, W. Seidel, L. Oberau) performed series of analytical/experimental studies of SSC as neutrino detector. Most of the results were confirmed by the French group (Ecole Normale Superieur/College de France/CEA, Saclay/Annecy).

The detection of neutrinos is the most demanding application of SSC due to requirements of:

-very high sensitivity of a few hundreds eV

-considerable mass, say a few kilogram

-very efficient background rejection

Thus, important improvements are necessary, but due to ten years of experiments, we at least known where and how these improvements can be obtained. Some of the promising techniques have been already experimentally studied with some success.

The most important are:

-improvement of the read-out electronics by use of low temperature techniques e.g., SQUID's

-diminishing the metal specific heat by operating in temperature << 1°K, i.e. in dilution refrigerator

-improvement of the grain quality e.g. better size selection, more spherical grains, rarer surface defects

-control of collective effects, i.e. interactions between grains in the densely packed collection of grains ("diamagnetic effect," "thermal avalanche effect")

-diminishing the radioactive background, by use of purer materials and better control of contamination during the grain production.

We studied the background problem for the experiments performed at reactor and concluded that intrinsic radioactivity is dominating. For the neutrinos from reactor, $\bar{E}_\nu$ = 2 MeV and f = $10^{12}$-$10^{13}$ $\nu/(cm^2 \times sec)$ we expect signal/background = 10 for chemical purity of 99.995%. It should be pointed-out, that use of the source which provides a high flux, say $10^{15}$-$10^{16}$ $\nu/(cm^2 \times sec)$, burst of neutrinos can considerably diminish the background problem. The purity of 99.95% which is easily available commercially may be sufficient in the applications of interest to our project.

The groups in Munich are active in areas such as:

-production of better grains

-lower noise (l. nitrogen/l. helium coued) read-out electronics

-tests of SSC at dilution refrigerator, specifically the studies of "thermal avalanche effect"

The group in MPI consists of two senior physicists and one technician. However, it is expected that five more physicists will join it in spring 86. Group in TU consists of two senior physicist and two post-docs.

The groups in France are involved in:

-developing soft x-ray imaging device based on SSC which will feature 256 channels of cheap, very sensitive room temperature read-out electronics

-studying "diamagnetic effects"

-preparing very low temperature tests

All together, the French collaboration consist of over 10 physicists (some part time) and a few technicians.

Furthermore, rumors indicate that three groups in USSR are developing superconducting particle detectors (Erevan, Leningrad, Moscow). More specifically, the Leningrad group is studying the use of superconducting detectors of neutrino. This effort by Russian groups was started eight years ago. However, not much is known about their results as there were no open publications.

2.2.2.2 Experimental tests of SSC in UBC, Vancouver: An Overview

Department of Physics in University of British Columbia, Vancouver has a relatively good low temperature facilities, e.g. 3 dilution refrigerators, about 10 l. helium - 4 cryostats, 4 RF-SQUID's. Some 20 physicists and graduate students work in the field of low temperature physics. Furthermore, well trained technicians and good engineering students are available to help with experiments. The group of Prof. B. Turrell consists of two senior scientists and two graduate students. They have a good dilution refrigerator and two helium-4 cryostats. The general cryogenic equipment is good and general electronics equipment adequate but somewhat old (mostly from 1970-1975). They have a seven year old RF-SQUID produced by SHE. Furthermore they have one data acquisition system on-line with University computer but could use one more PC (best IBM compatible with STD bus). An important element in the UBC program is possibility to use facilities of Canadian Meson Factory - Triumf, which is

located very close to Physics Department.

The experimental program in UBC will concentrate on the improvement of the read-out electronics by use of the low temperature techniques, e.g. SQUID's. After successful development of a read-out able to detect the change of state of a few micron grains ($R = 2\text{-}4\ \mu m$), we will perform studies of the SSC detector irradiated with $\gamma$-rays. Further experiments will use minimum ionization particles (in collaboration with H. Olin, Triumf). This first period of studies will take until January/February 1986. We hope, that the funds of the SAO subcontract will be enough to perform the two first of above mentioned tests.

Provided that adequate funding is available we will try for the SSC tests at dilution refrigerator temperature. The improvement of SQUID read-out sensitivity to say, $5 \times 10^{-3}\ \phi_0 \sqrt{Hz}$ and the use of $T \leq 200$ millikelvin should permit us to reach the landmark sensitivity of a few hundreds eV, i.e. energy sensitivity permitting detection of neutrino with $E_\nu \geq 5$ MeV. Technically, this may require use of DC-SQUID's better shielding and the use of gradiometer for read-out loop. Furthermore, the use of low $T_c$ metals as Cd, Zn, Ga, Al may be necessary. We hope to reach this landmark sensitivity in late spring/summer 1986.

Further development will require production of grains for 1 kg detector, as well as development of multichannel SQUID read-out. The transfer of know how/collaboration with groups which operate multi-SQUID systems may be necessary (SHE, University of Chicago, IBM). The optional solution would be to use the collective effects ("thermal avalanche process"). The study leading to a neutrino detector prototype may be finished in fall/winter 1986/1987.

2.2.2.3 Preliminary Tests of SQUID Read-Out: Experiments in UBC until January 1986

The detection of a few MeV neutrinos, requires electronic read-out able to detect the change of state of grains with R = 2-3 $\mu m$ (see Section 2.2.2.5 - Appendix I). In the following state of art in SSC electronic read-out and proposed experimental program in UBC is presented.

The change of state of a single grains was detected using room-temperature, Si-Fet change sensitive amplifiers. The hundred nanoseconds voltage pulses with amplitude of:

$$\Delta V \approx 10^{-7} \frac{\Delta\phi}{\Delta t} \times \left(\frac{R_g}{R_{loop}}\right) \qquad (1)$$

were observed, wherein $\Delta\phi \approx TR_q^2 \times H$ is the change of magnetic flux, $\Delta t \approx 100$ nsec is integration time of amplifier and $R_g/R_{loop}$ gives the coupling between the grain of radius $R_q$ placed inside the loop with characteristic dimension of $R_{loop}$. The best preamplifiers have a figure of merit of 50 $\phi_o$ where $\phi_o = 2 \times 10^{-7}$ G x cm² is quantum flux. Using read-out lines with $L \approx 1$ mm the change of state of $R_g \approx 5\mu$ grains was reliably observed by both Paris and Munich groups. It is believed, that by further improvements, say using GaAs Fet's, the figure of merit of 10 $\phi_o$ and detectability of $R_q \approx 3\mu m$ grains can be achieved. Unfortunately, with $R_{loop} < 1mm$ the kilogram detector will require a few thousands of channels. This, "brutal force" method is being studied by Paris group.

Since the grains are in a metastable superheated state, the change of magnetic permeability is permanent, thus can be conveniently detected by SQUID's. With Dr. R. Nest, Copenhagen University we analyzed the possibility of SQUID read-out, and concluded (see Section 2.2.2.5 - Appendix I) that it may be

better than the room temperature electronics. The first experiments have been performed by IBM group. They placed R = 5 $\mu m$ grain of tin in the field of 40G and used the small surface magnetic gradiometer coupled to DC-SQUID to measure the change of state. They observed signal to noise ratio of a few millions. This experiment confirms possibility of using SQUID's for read-out of grains but the used read-out loop is to small to be of practical value.

The aim of experiments performed in UBC in 1985 is three-fold;

- detect flipping of $R_g \leq 3\ \mu m$ grains with a small, say 1 cm diameter, loop;
- obtain the information about the size of smallest detectable grains as function of loop diameter;
- design the SQUID read-out system which will be able to detect change of state of single grain within a 100 g colloid sample.

The first experiments in UBC were performed in March/April 1984. The experimental set-up consisted of :

- smaller 1°K cryostat with SSC sample
- bigger 4.2°K cryostat with SQUID sensor and magnetic field coil
- means of temperature control and monitoring
- superconducting shielding

The read-out loop were 3 turns of superconducting coil ($\phi \approx$ 5.4 cm) with $L_{coil} \approx 3\ \mu H$. We observed the following SQUID noise:

- $5 \times 10^{-3}\ \phi_o/\sqrt{Hz}$ for T = 4.2°K and no field
- $10^{-2}\ \phi_o/\sqrt{Hz}$ for T = 4.2°K, H $\approx$ 300 G
- $5 \times 10^{-2}\ \phi_o/\sqrt{Hz}$ for T $\approx$ 1.0°K, H $\approx$ 300 G

When the strong magnet is placed close to devar we observed no shift in SQUID,

i.e. the shielding was judged adequate. The noise spectrum was not measured, but we suppose that the main source of noise is vibration of the cryostat, especially when pumping. Furthermore we observed very strong influence of the helium level of SQUID. Drift of SQUID as big as 0.1 $\phi_0$/sec were observed when pumping helium bath. Unfortunately, it was impossible to use the termometer (carbon resistance) inside the 1°K cryostat, because the attempts to measure the resistance were introducing $\Delta\phi \approx 0.1\ \phi_0\sqrt{Hz}$ noise. We have been, however, able to see the hysteresis curve due to flipping many grains.

During these first experiments in UBC we:

- measured hysteresis curve due to flipping many grains using SQUID
- reached sensitivity of 0.1 $\phi_0/\sqrt{Hz}$, i.e. factor 500 better than the best results of Munich/Paris groups

In the same time, our sensitivity is at least three orders of magnitude worse than in good commercial systems. The similar noise of 0.1 $\phi_0/\sqrt{Hz}$ was reached in experiments (Chicago, IBM) with one square meter read-out loop, i.e. with surface 400 bigger than used in UBC. In one word, we learnt how not to do this experiment. Specifically, we realized the need of placing the sample on cold finger in vacuum and of diminishing the vibrations when pumping helium-4 bath.

The interior of the cryostat was redesigned, and was ready for cold runs at the beginning of June 1985. Because of several delays, we will start the experiments in the beginning of September.

First tests will be:

- measurement of SQUID noise in different experimental conditions e.g. T = 1.0 - 4.2°K and H = 0 - 500 gauss

-detection of a change of state of bigger, $R \simeq 10$-$15\ \mu m$, grains using large loop ($\phi_{loop} = 5$ cm)

-detection of a change of state of smaller, $R \simeq 3$-$4\ \mu m$, grains placed in a narrow loop ($\phi_{loop} = 1$ cm).

The SSC sample will consist of a small number, say about 50, grains. The reproducibility of the grain flipping will be studied. We think that by 1 October 1985 we will eliminate some major noise sources, e.g. vibrations and we hope to reach the sensitivities of:

-$5 \times 10^{-3}\ \phi_o/\sqrt{Hz}$ with $\phi_{loop} = 1$ cm

-$5 \times 10^{-2}\ \phi_o/\sqrt{Hz}$ with $\phi_{loop} = 5$ cm

The experimental set-up will be modified during October and experiments restarted 15 November 1985. In this second series of experiments we will perform tests with $\gamma$-sources. We will use two different sources, e.g. $Ga^{67}$ with $t_{1/2}$ = 6h and $E_\gamma \approx$ 93 keV and some soft $E_\gamma \leq 20$ keV source. We will use a larger, say 10g sample of Sn-grains with well defined size. The quantum detection efficiency will be estimated for variable:

-grain size ($Rg = 3$-$10\ \mu m$)

-temperature/magnetic field

By end of 1985 we hope to reach the sensitivity of:

-$10^{-3}\ \phi_o/\sqrt{Hz}$ with $\phi_{loop} \approx 1$ cm

-$10^{-2}\ \phi_o/\sqrt{Hz}$ with $\phi_{loop} \approx 5$ cm

To achieve these sensitivities we will use both magnetometer and gradiometer loops. Please notice, that with sensitivity of $10^{-3}\ \phi_o/\sqrt{Hz}$ we will reach the intrinsic noise of RF-SQUID available in UBC. Further improvements will require considerable change of experimental set-up, e.g. purchase of DC-SQUID; magnet-

ically and HF shielded room.

2.2.2.4 <u>What next</u>?

The experiments in UBC, Vancouver will permit the preliminary estimates of the limits to the SQUID read-out. For the design of the $\nu$-detector we need further data/improvements in:

- grain production/selection methods
- uses of very low temperature, $T \leq 100$ mk
- uses of collective effects e.g. "thermal avalanche effect"
- reasonable flux ($f_\nu \geq 10^{10}$ $\nu/cm^2$ x sec), higher energy $\nu$-sources ($E_\nu \geq 5$ MeV)

Some of these tasks can be performed in UBC, Vancouver but will require adequate funding, beyond the present subcontract awarded by SAO to UBC. Others may be performed in collaboration with groups knowledgeable in material sciences. These will be discussed in later reports.

2.2.2.5 - Appendix I

## A Few Comments About the Requirements Upon the SQUID Read-out

When neutrino scatters coherently off nuclei, the average energy transfer

$$\bar{E} = \frac{1}{3} \frac{E_\nu^2}{m_A} \tag{A.1}$$

where $E_\nu$ is neutrino energy in MeV and $m_A$ the target nuclei mass. Thus for 5 MeV neutrinos, we have $\bar{E} \approx$ 330 eV and 90 eV for Al and Sn, respectively.

The energy threshold depends strongly on the system temperature, $E_{th} \propto C_v(T)\Delta T \propto T^2$ for $T \leq 1$ K. Neutrinos with energy higher than 10 MeV can be detected by a detector cooled to 0.4°K. Detection of neutrinos with $E_\nu \leq 5$ MeV, necessitates working in lower temperature. Through this appendix, we will assume T = 50 mK a system temperature easily obtained in commercially available dilution refrigerators for mass of samples smaller than 10 kg. These cryostats have temperature stability of better than one mK. There are several sources of thermal noise: the temperature instability of the helium bath, temperature fluctuations, and external phonon absorption. If we require that the grain must be heated by at least 12.5 mK to produce a change of state, these temperature noise effects are negligible[1].

The superconducting grain placed in the external magnetic field, H, is equivalent to a magnetic dipole; the disappearance of this dipole generates a detectable E.M.F. Since the grains are in a metastable superheated state, the change of magnetic permeability is permanent, thus can be conveniently detected by SQUID's. We can determine the change in flux at the loop induced by the change in state of a single grain of radius $r_g$ inside a circular loop of radius $r_L$.

$$\Delta\phi_{loop} = - \frac{HV_g}{2r_L}\left[\frac{E(k)}{1-a} + \frac{K(k)}{1+a}\right] \qquad (A.2)$$

where a, d, and k are defined in terms of A, the distance from the grain to the loop axis and D, the distance from the grain to loop plane: $a = A/r_L$, $d = D/r_L$, and $k^2 = 4a/\left[(1+a)^2 + d^2\right]$. E(k) and K(k) are elliptical integrals. For a grain in the center of the loop, this simplifies to:

$$\Delta\phi_{loop} = - \frac{1}{2\pi}\Delta\phi g \frac{r_g}{r_L} \qquad (A.3)$$

where $\Delta\phi g \approx \pi r_g^2 H$. H is the magnetic flux expelled from the grain.

For a superconducting loop coupled by a flux transformer to a SQUID, the change in flux observed by the SQUID depends upon the number of turns in the loop, N, and the inductances, L, of the SQUID, the loop, and the transformer,

$$\Delta\phi_{SQUID} = N \frac{L_{SQUID}}{L_{SQUID} + L_{loop} + L_{parasitic}} \Delta\phi_{loop} \qquad (A.4)$$

We will require that the signal produced in the SQUID by a grain flip, $\Delta\phi_{SQUID}$ exceed the system noise by a factor 10. The intrinsic noise in a DC-SQUID is very small,

$$\Delta\phi_{noise} \approx 5 \times 10^{-6}\ \phi_o/\sqrt{Hz} \qquad (A.5)$$

where $\phi_o = 2.07 \times 10^{-7}$ G cm² is a flux quantum. For loops with a radius greater than 10 cm, other sources of noise, mechanical vibrations, and the pick-up of magnetospheric fluctuations, dominates and contributes between $10^{-4}$ and $10^{-2}$ flux quanta per $\sqrt{Hz}$. Thus the choice of loop diameter and the observed read-out system noise defines the minimal size of the grain and the energy threshold.

The optimal read-out configuration may consist of several small read-out loops in parallel. Magnetic gradiometers can be used to reject external magnetic noise. These improvements would reduce the $\Delta\phi_{loop}$ required for a clean detection; hence, allow the use of smaller grains and the detection of less energetic neutrinos.

Natural radioactivity is the major source of background. Radioactive decays produce particles with kinetic energies of many MeV. These particles are likely to flip not one but many grains. By filling only a fraction of the volume of the loop with the colloid, and by requiring that the both multiple flippings of grains and the flipping of a single grain near the surface of the colloid (which produces a stronger signal) are rejected, the contribution of natural radioactivity to the background can be markedly reduced. Numerical analysis shows that the optimal detector looks like the surface of revolution of a filled pretzel and occupies 30% of the loop volume.

Only a small fraction of the colloid ($\approx$ 10%) is composed of superconducting grains, the rest of the colloid is composed of the dielectric, which prevents grains from transferring heat to their neighbors. Thus only a small fraction of the volume of the loop is allotted to grains. The count rate per SQUID will scale with the mass of the grains within the loop connected to the SQUID. The mass of superconducting grains within each loop, $M_g$, depends upon the filling factor of grains in the colloid, $\alpha_{coll}$ and the fraction of the volume of the detector allocated to the colloid, $\alpha_{loop}$

$$M_g = \frac{4\pi}{3} r^3 L \rho \alpha_{coll} \alpha_{loop} \approx 0.04\pi p r_L^3 \qquad (A.6)$$

where $\rho$ is the density of the element used in the superconducting grain.

Because of the high cost of the SQUID's and the difficulties of operating more than ten SQUID read out systems, we wish to maximize the count rate per SQUID. Since the count rate scales as the mass of the detector and the incident particle velocity, we wish to maximize $M_g$. This entails using the largest possible loop. The price of a large loop is a higher energy threshold. If we wish to detect a particle of given mass, the maximum energy threshold that would allow any detection scales as the square of the energy of the incident particle. Hence, the mass of grains attached to each SQUID scales as $E_\nu^6$, and the count rate per SQUID scales as $E_\nu^8$. This strong neutrino energy dependence motivates us to look for the possibility of neutrino sources with energy higher than reactor neutrinos.

## 2.2.3 Neutrino/Superelectron Interaction Approach*

### 2.2.3.1 Introduction

A flux of neutrinos, in Stodolsky suggestion, exerts a torque on the spins of electrons which is linear in the weak interaction constant $G_F$ and is additive over the particles, so in a bulk material a global effect should be obtained. The main reason to investigate this effect on a superconductor stems from the very low energy values of superconducting gaps ~ 1 meV. In a qualitative way the torque on the spins of superconducting electrons could eventually flip their orientation leading to destruction of Cooper pairs, which are formed by electrons having opposite momenta and spins.

### 2.2.3.2 Study Task

Obtain a quantitative estimate of the effect described in Section 2.2.3.1.

### 2.2.3.3 Results of the Preliminary Analysis

a) Microscopic Theory Approach

In a flux $\vec{J}$ of neutrinos on electron acquires a potential energy

$$h = \pm \sqrt{2} \; \frac{G_F}{c} \; J$$

formally similar to that of a magnetic dipole $\mu$ in a magnetic field $\vec{H}$

$$h = \pm \mu H$$

*Contributed by F. Fuligni

and one must solve the problem by adding to the BSC Hamiltonian a term

$$h\Sigma\ (n_{k\uparrow} - n_{k\downarrow})$$

In this way Sarma (1963) evaluated the influence of the field on the critical temperature $T_c$. I have studied the influence of the field on the density of Cooper pairs. A complete solution has not yet been worked out. Approximate results, obtained by series expansion, seem to indicate that the breaking parameter, to lowest order, goes like $h^2$ which is not very encouraging.

b) Macroscopic theory solution

A solution valid at temperatures T near $T_c$ has been obtained with a thermodynamic argument starting from the Ginsburg-Landau free energy

$$F = Fn + a|\psi|^2 + \frac{1}{2} b|\psi|^4 + \frac{h^2}{4m} |\nabla\psi|^2$$

where Fn is the free energy of normal electrons and $|\psi|^2$ is the density of super electrons. The effect of the interaction was included in Fn considering a relationship similar to that for the paramagnetism of electrons:

$$Fn = 3\left(\frac{\pi}{3}\right)^{2/3} \frac{m\ h^2}{h^2\pi^2} \left(N - 2|\psi|^2\right)^{1/3}$$

where N = total number of electrons per unit volume. By minimizing F with respect to $|\psi|^2$, assuming a uniform distribution in space ($\nabla\psi$=o), we get for the variation in the number of Cooper pairs due to h

$$\delta|\psi|^2 \simeq \frac{h^2}{7(kT_c)^2} N$$

and the $h^2$ dependence is confirmed giving however an effect too small. This result can be linearized by keeping inside the superconductor a constant magnetic field to which the flux of neutrinos is superimposed. This implies using superconducting strips with thickness of the order of the penetration depth, in presence of a magnetic field. The solution of this problem gives, for $\mu H \simeq kT_c$,

$$\delta|\psi|^2 \simeq \frac{1}{7}\left(1 + \frac{1}{24}\lambda\right)\frac{h}{kT_c} N \qquad \left(\lambda = \frac{Hd}{H_c\ \delta}\right)$$

and we find that less than 1 pair is broken for cc of superconductor!

2.2.3.4 Conclusion

At this stage it is not worthy to further consider this option as a possible immediate solution for building a detector. I will personally try to complete the solution in the hope that, in due course, some way may be found to circumvent the difficulty. Because of the severe limitations, time-wise and money-wise, of the Raytheon/SAO neutrino program, it is recommended that no additional work be performed (neither theoretical nor experimental) on this sensing method.

2.2.4 The Silicon Bolometer

This approach was proposed by Cabrera, Krauss and Wilczek in 1984 (HUTP-84/A077) and appeared later-on in Phys. Rev. Lett. Vol. 55, No. 1, 1 July 1985, pp. 25-28. It consists of measuring the temperature changes in a slab of crystalline silicon due to the elastic scattering of neutrinos off the electrons in the slab. By keeping it at dilution refrigeration temperatures (in the range 1 to 10 milli °K), measureable temperature changes in macroscopic amounts of material result, even for low-energy neutrinos ($\leq$ 0.41 MeV). The authors have concluded that this new detector is also suitable for low-energy neutrino interactions including coherent nuclear elastic scattering. The fundamental properties of this sensor can be summarized as follows.

- A silicon block is well suited for thermometric detection of recoil electrons and lower-energy recoil nuclei, due to interactions with neutrinos.

- Silicon is readily available with extremely high purity and in large quantities. There is a nearly total absence of radioactive impurities. There are strong limitations in the level of induced radiation.

- The detection scheme is based on observing temperature rise caused by thermalization of recoil energy throughout macroscopic silicon mass. Typically, energy transfer of 100 KeV will raise the temperature of 1 kg silicon block (initially at 1 milli °K) of about 4 milli °K.

- The measurement of temperature rise in silicon block can be performed by using thin-film ring made of tungsten (with transition temperature of 15 milli °K), deposited onto silicon block and monitored inductively with a SQUID.

- The flipping of tungsten ring into normal status increases of a factor of about 5 the mutual coupling between a primary and a secondary of a measurement

transformer, with the SQUID at its output.

• Stack of several silicon blocks make it possible to distinguish between neutrino events and cosmic-ray (muons) events. In fact, in the neutrino scattering case, recoil electrons and nuclei lose their energy in less than 1 mm and excite only one block. Muons will excite many blocks.

• Single SQUID read-out can monitor several individual silicon blocks, by monitoring several different pilot-tones (a tone frequency for each block).

The scheme of principle of the proposed bolometer is illustrated in Figure 8. The study activity on the bolometric approach includes the following specific tasks.

• Continue analysis of threshold sensitivity.

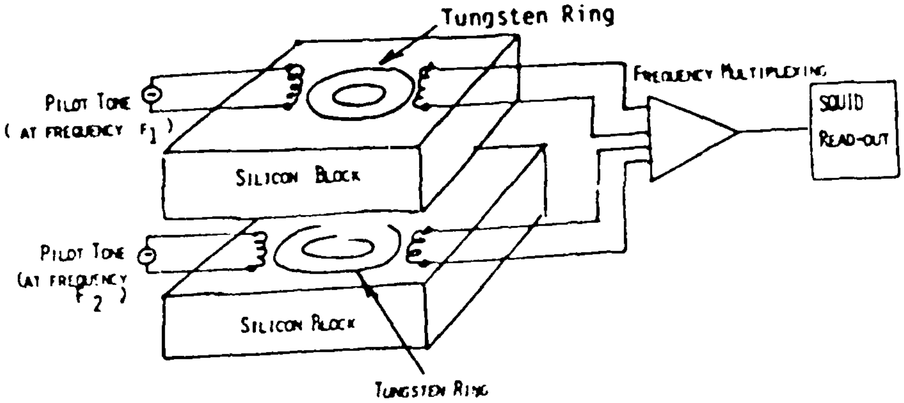
• Perform the preliminary design of single silicon block detector of mass 1 kg for detection of non-neutrino sources to allow measurement of the thermodynamic properties of silicon in the milli °K regime, as well as calibration of thermometry, timing, thresholds, etc.

• Perform the conceptual design of a reactor experiment with 10-to-100 kg active detector, to allow tests of shielding approaches and detection of coherent scattering of neutrinos.

If adequate funding is made available for hardware development, a prototype of the 1 kg detector could be made ready for tests as early as Fall 1986. The construction then of the 10 kg detector could be completed by late 1987.

Figure 8

SCHEME OF PRINCIPLE OF BOLOMETER



## 2.3 PLAN FOR 2nd QUARTER ACTIVITY

Next quarter activity will have a focus and a strong emphasis: to start performing laboratory tests on the magnetic interaction sensor (at SAO and especially at FERMILAB) and on the SSC calorimeter (at UBC).

For the magnetic sensor, we plan to perform room-temperature and $4^{o}$K measurements on the achievable sensitivity, with sources other than neutrinos. The tests at FERMILAB will be performed with a $4^{o}$ K SQUID loaded with a small-size, high-permeability target. The results will be extrapolated to realistic target sizes, such as the 45Kg and 1,000 Kg targets that we have under consideration for experiments that will use actual neutrino sources. System sensitivity to weak magnetic fields will be measured at FERMILAB by introducing into the SQUID cryostat a small induction loop fed by an external signal generator. When the results from these tests will become available, we will be able to perform the design of the sensor that will be used with an actual neutrino source, such as TSTA at Los Alamos.

For the SSC calorimeter, we plan to proceed to the planned laboratory tests on the response of Sn grains to gamma-rays. We will introduce a gamma-ray source (with known decay time) into the cryostat of the calorimeter, with SQUID read-out. The grain response will be investigated as a function of temperature, grain size and filling factor. Measurements will be performed on the ability of the SQUID to detect the change of state of grains, a few micrometer in diameter. At the same time, we will continue in our analysis of the SQUID read-out approach.

For the silicon bolometer, the activity will remain strictly analytical, but it will see the inception of an effort leading to the conceptual design of a single-silicon-block detector, with a mass of 1 Kg, with the aim of establishing fundamental thermodynamic properties of the silicon slab, for use in the follow-on design of a sensor configuration that is suitable for use with neutrino sources.

## 3. PRELIMINARY CONCLUSIONS AND RECOMMENDED COURSE OF ACTION

After three months of project activity, we can tentatively say that laboratory tests with neutrino sources of opportunity should preceed any kind of field test. After having visited NTS, Las Vegas, NV on 8/28/85, we have now a more realistic understanding of the complexity and cost of such an experiment. What is now better appreciated is the need to integrate tightly our experiment with at least a dozen of other experiments, scheduled to take place on the occasion of the same event. Even if our sensor is self-contained and totally separate from the other instruments, still it must share with them several functions, such as the command/control channels of the microwave link that NTS uses for the remote control of all instruments associated with the same event, as well as house-keeping telemetry channels. In addition, the overall sequences of steps preceeding the actual observation of the event, must be rehearsed in repeated dry-runs that take usually four months (and often six months) prior to event time.

The low-energy neutrino source available at LANL (the so-called TSTA tritium source) releases a neutrino flux that, at a distance of the order of one meter, is a couple of orders of magnitude weaker than the flux expected, in the first second, from a 150 Kton detonation, at a distance of about 1/2 kilometer. With TSTA, we could, however, use an integration time as long as several days (if necessary), to compensate for the lower flux.

Under the assumption (not yet corroborated) that the critique presently underway of the physical foundations of the magnetic interaction approach will provide an encouragement to go experimental, we would recommend to try the prototype of the magnetic sensor at LANL with TSTA, as early as feasible, maybe as early as Spring 1986. Work at UBC on the SSC calorimeter should be continued, possibly at an accelerated pace, if the results next quarter are promising enough, and if the project budget will allow an increased expenditure rate for this approach.

## 4.BIBLIOGRAPHFIC REFERENCES

STODOLSKY, L., 1975, Phys. Rev. Lett., Vol 34, N.2, pp 110-112, 13 January.

BRAMANTI, D., 1984, Magnetic Detection of Low Energy cosmic neutrinos, SAO Technical Note TP84-003, March.

DRUKIER A.K. and L. STODOLSKY, 1982, MPI-PAE/PTh 36/82 (also in Phys. Rev., D, pp. 2295-2309, December 1984)

CABRERA B., L.M. Krauss and F. Wilczek, 1985, Bolometric detection of neutrinos, Phys. Rev. Lett. Vol 55, N.1, pp 25-28, 1 July.

MOSELEY H. et al, 1984, J. Appl. Phys., 56, 1257.

MC CAMMON, D., 1984, J.Appl. Phys., 56, 1263.

GROSSI, M.D., 1982, Investigation of Techniques for the measurement of mechanical effects of low-intensity e.m. waves and corpuscular radiation, SAO Rep. NASA-CORE Grant NSG-7176, March 31 (rev. August '83)

FULIGNI F. and M.D. GROSSI, 1984, High Sensitivity geometric Displacement Sensors for the measurement of weak forces and torques, SAO Rep NASA-IRP Grant #671-7056, August.

RAYTHEON CO. , 1983, Analytical Study of Mechanical Effects of Corpuscular Radiation, Proposal P2463 to DARPA, October.

FIORINI E., T.D. Niinikoski, 1983, CERN-E8/83-180, pp 1-14, November (also published in NIM, 1984).

BOZORTH R.M., 1951, Ferromagnetism; Publisher: D. Van Nostrand Co., New York, N.Y.